

Characterizing and Comparing Landscape Diversity Using GIS and a Contagion Index

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ABSTRACT. The purpose of this study was to examine the pattern and changes in forest cover types over the last two decades on three landscape level physiographic provinces of the state of Alabama, USA: (i) The Great Appalachian Valley Province, (ii) The Blue Ridge Talladega Mountain Province, and (iii) The Piedmont Province. Studies of spatial patterns of landscapes are useful to quantify human impact, predict wildlife effects or describe various landscape features. A robust landscape index should quantify two distinct components of landscape diversity: composition and configuration. Composition refers to both the total number of "patch" types (i.e., forest cover types) and their relative proportions in the landscape, whereas configuration refers to the spatial pattern of patches in the landscape. The U.S. Forest Service conducts periodic surveys of forest resources nationwide from plots distributed on a 3 mile by 3 mile (4.8 km by 4.8 km) grid randomly established within each county. Using forest inventory and analysis survey data stratified by physiographic province, a relative contagion (RC) diversity value and its variance were calculated for each province for the survey years 1972, 1982, and 1990. One-way analysis of variance was used

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for hypothesis testing of RC values across time and between provinces. A view of each landscape at each point in time was generated with GIS **software** using Thiessen or proximal polygons of the forest cover types identified at each survey point on the landscape. *[Article copies available for a fee from The Haworth Document Delivery Service: 1-800-342-9678. E-mail address: getinfo@haworth.com]*

INTRODUCTION

Resource professionals have been expanding current management approaches to address landscape-level concerns and issues (Salwasser 1990). With the recognition of such problems as loss of biodiversity, climate change, and ecosystem degradation, a necessary evolution in management scale has come about. Today, resource managers are designing programs that consider the well-being of an ecosystem. The limitations of species-based management and narrowly focused project-by-project, permit-by-permit analysis have led to the development of geographically targeted approaches (Oliver 1992; **Ticknor** 1992). Based on watersheds or other ecological units rather than political boundaries, such approaches provide the tools and conceptual structures for ecosystem management and sustainable forestry (Council on Environmental Quality 1990).

Sustainable forestry involves the application of **ecological/silvi-**cultural principles, social/cultural values, and economic realities in long range planning as **well** as day to day decision making at regional, landscape, and **local** scales (**Agee** and Johnson 1988). To manage forest resources for sustainability, as **with all** types of management, requires the input of quantitative information. Assessing diversity at the landscape scale, valuable input for sustainable forest management, has recently gained much attention (**Naveh** and **Lieberman** 1994). Further developments are needed in the area of landscape measures of diversity, especially in terms of distributional properties so hypothesis tests can be conducted.

A robust landscape index should quantify two distinct components of landscape diversity: composition and configuration. Composition refers to both the total number of land use categories or "patch" types and their relative proportions in the landscape, whereas configuration refers to the spatial pattern of patches in the landscape (Li and, Reynolds 1993). Contagion, as defined by

O'Neill et al. (1988), measures the extent to which landscape elements are aggregated or clumped. Higher values of contagion generally result **from** landscapes with a few large, contiguous patches, whereas lower values usually characterize landscapes with many small patches. Also, contagion values, in general, decrease as category proportions become more even. To date, only a handful of contagion indices have been proposed, and in no cases have distributional properties been examined.

Landscape diversity is inexorably linked to geographic information. Geographic Information Systems (GIS) are today an important tool for assessment, management, and monitoring. Layers of **information** can be combined in various ways to get a picture of the whole, or a visual perspective on change, or to highlight critical features, etc. For this paper geographic information, utilizing a GIS, is exploited to highlight regional features (**physiographic** provinces), landscape features (sample points and forest cover types), and for **assessment**.

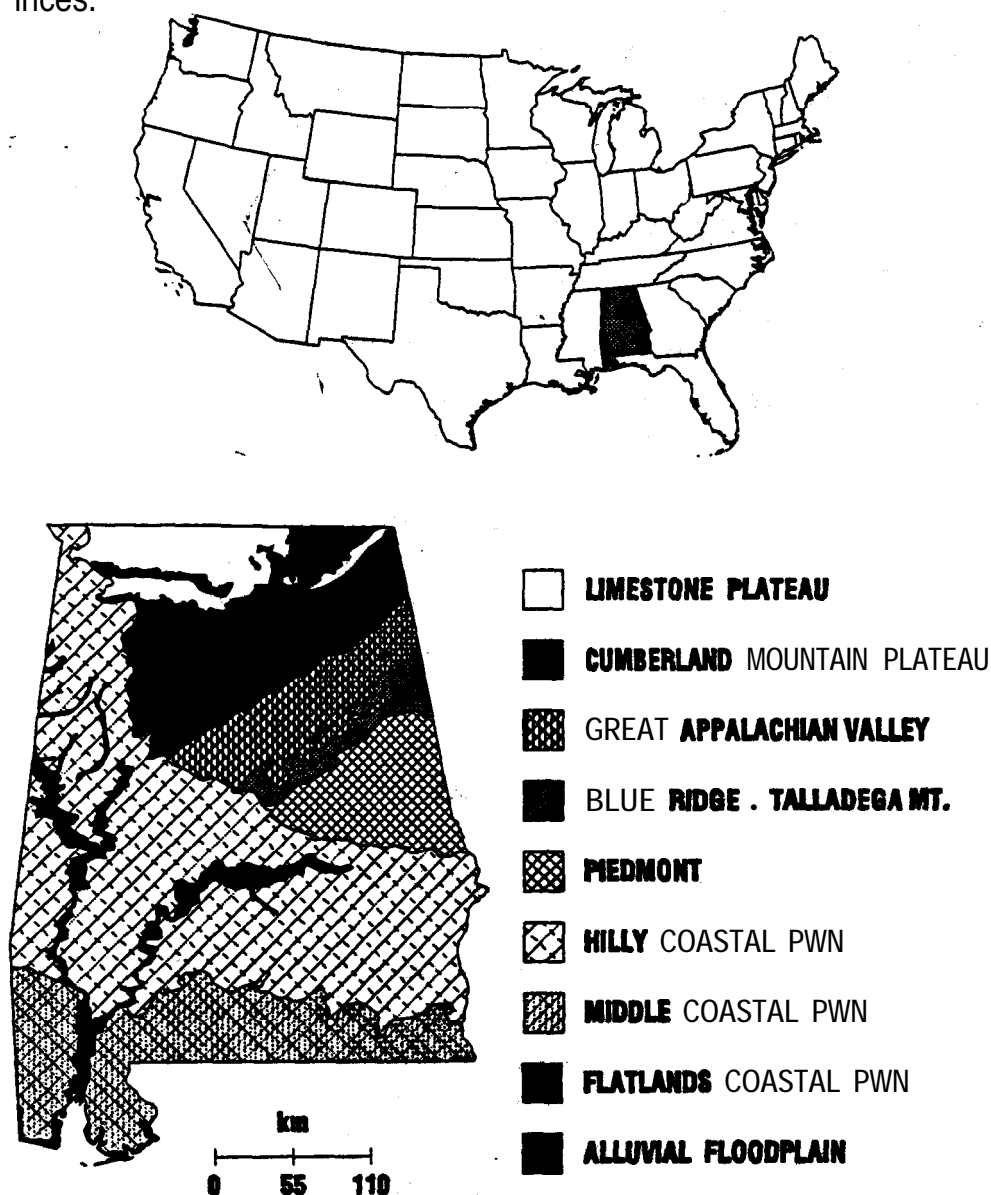
MATERIALS AND METHODS

Physiographic Provinces and Forest Cover Type Data

To assess landscape habitat diversity one must necessarily specify the spatial boundaries of a landscape chosen for study. For geographically targeted units, the boundaries may coincide with those of an **island**, **the** word, in its ecological sense, connotes any environment entirely surrounded by another with strikingly different properties, the two being separated by a fairly abrupt boundary (Pielou 1975). Major patterns of landform-geologic material or "physiographic provinces" are well **defined** in the state of Alabama, USA (Hodgkins et al. 1979) (Figure 1). Three physiographic provinces were chosen for study: (i) The Great Appalachian Valley Province, (ii) The Blue Ridge-Talladega Mountain Province, and (iii) The Piedmont Province.

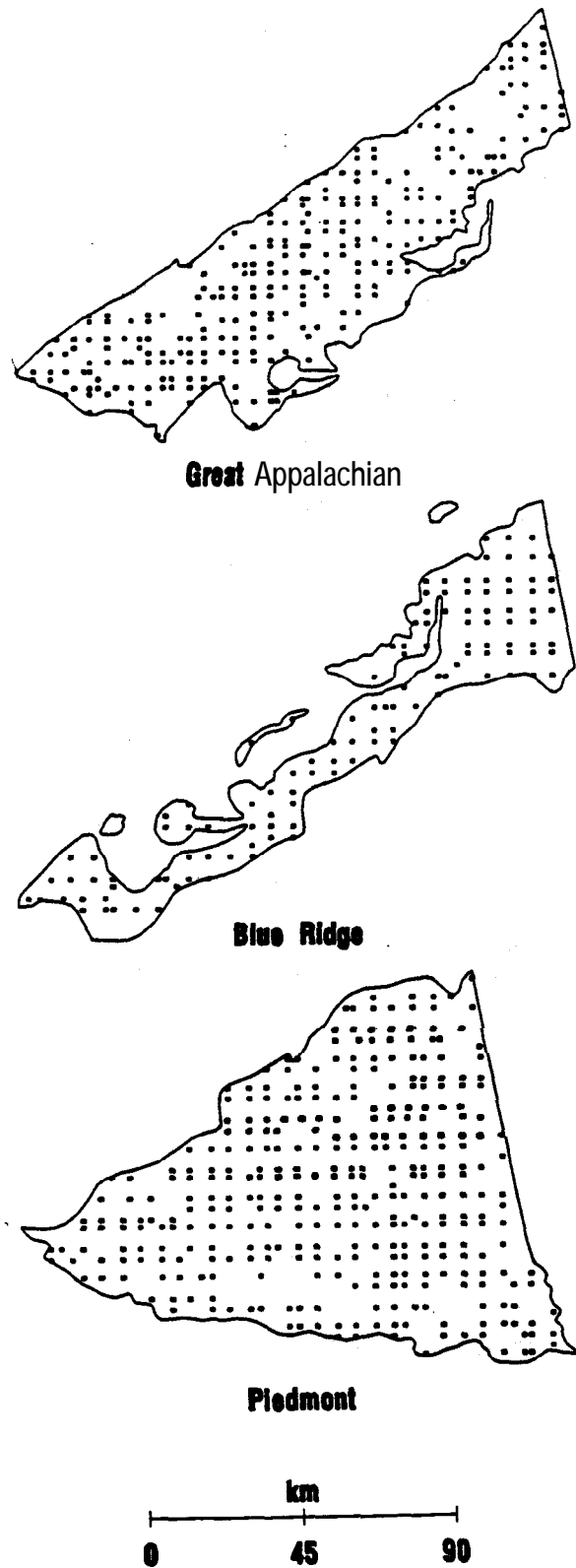
The Southern Forest Inventory and Analysis (SFIA) unit of the USDA Forest Service, Southern Research Station, conducts continuing inventories of forest resources in seven **midsouth** states. Data

FIGURE 1. State of Alabama, USA and its landscape physiographic provinces.



are collected from trees occurring on sample plots spaced across each state. Within each state plots are distributed on a **3- by 3-mile (4.8- by 4.8-km)** grid randomly established within each county. Locations of survey plots, stratified by physiographic province, are shown in Figure 2. Because each physiographic province crosses many county lines, survey plots within a province do not form a systematic grid. Hence the area represented by a plot may be polygonal in shape instead of square or rectangular. From the tree data a forest cover type is identified for each plot. Forest cover types on

FIGURE 2. Distribution of **SFIA** survey plots within the three physiographic provinces.



the study areas **are** listed in Table 1. Detailed descriptions of the SFIA data can be found in May (1990). In Alabama, the sixth forest survey was completed in 1990. The data from this and two previous surveys (1972 and 1982) were chosen for analysis.

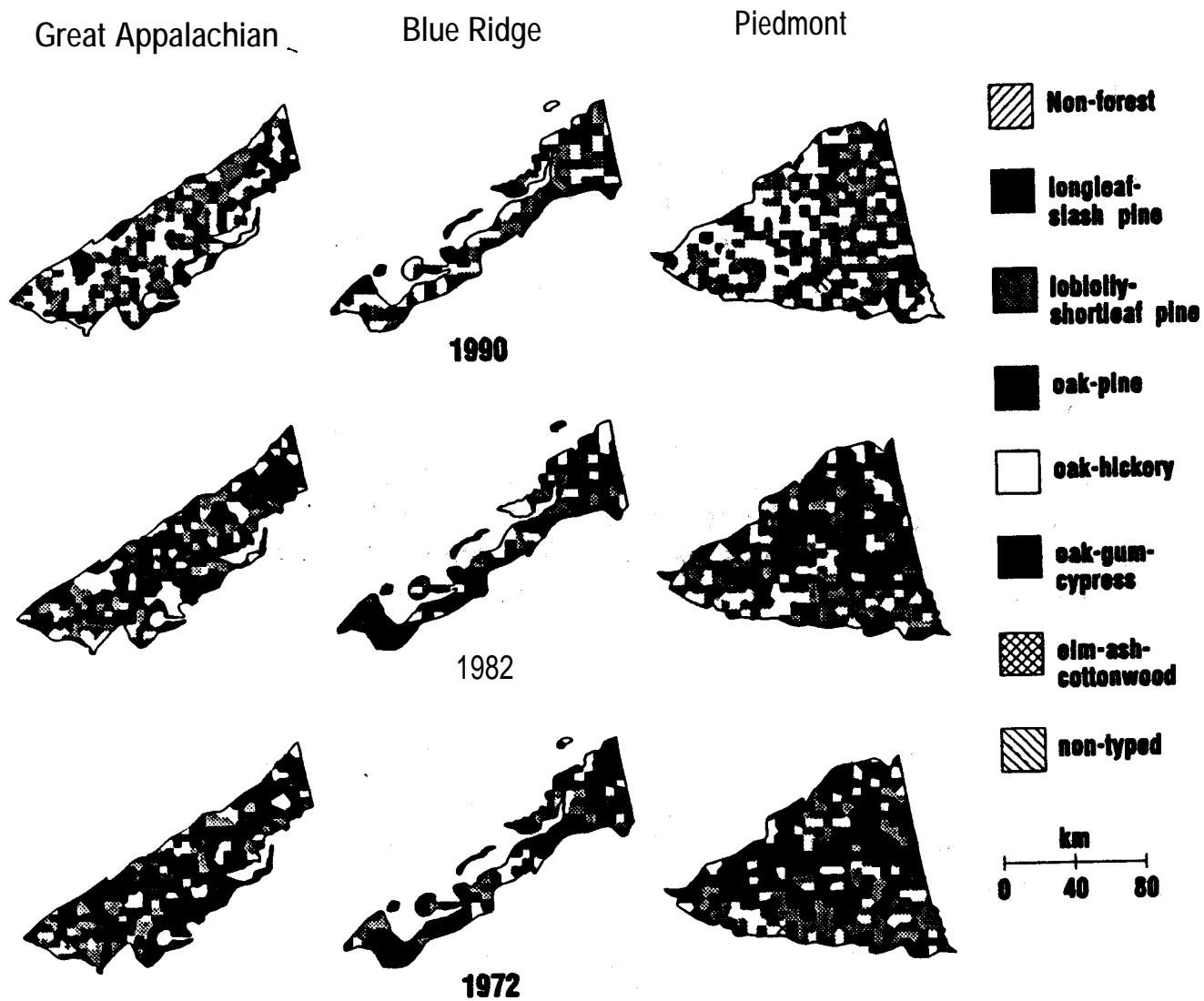
Viewing Forest Cover Types on the Landscapes

Thiessen **polygons can** be used to apportion a point coverage into regions known as Thiessen or proximal polygons (Environmental Systems Research Institute 1992). Each region contains only one point and has the **unique** property that any location within a region is closer to the region's point than to the point of any other region. Each physiographic province point coverage (see Figure 2) was apportioned into Thiessen polygons and like polygons (polygons of the same forest cover type) were colored the same to create a landscape level view of forest cover types for each province at the three survey years (Figure 3).

TABLE 1. USDA Forest Service general forest cover types occurring on these **physiographic** provinces in the state of Alabama, USA

General forest cover types	Species
Nonforest	
Longleaf-slash pine	<i>Pinus palustris</i>- <i>Pinus elliotii</i>
Loblolly-shortleaf pine	<i>Pinus taeda</i>-<i>Pinus echinata</i>
Oak-pine	<i>Quercus</i> sp.- <i>Pinus</i> sp.
Oak-hickory	<i>Quercus</i> sp.-<i>Carya</i> sp.
Oak-gum-cypress	<i>Quercus</i> sp.-<i>Liquidambar styraciflua</i>- <i>Taxodium distichum</i>
Elm-ash-cottonwood	<i>Ulmus</i> sp.- <i>Fraxinus</i> sp.-<i>Populus</i> sp.
Non-typed	

FIGURE 3. Forest cover type changes through time in three physiographic provinces based on **SFIA** survey data.



Contagion Index

The following contagion index, from Li and Reynolds (1993), quantifies both composition and **configuration** of the landscape:

$$RC = 1 + \frac{\sum_{i=1}^n \sum_{j=1}^n p_{ij} \ln(p_{ij})}{2 \ln(n)}$$

and

$$p_{ij} = p_i p_{j/i}$$

$$p_{j/i} = N_{ij}/N_i$$

where p_{ij} is the probability that a polygon of land use i is found adjacent to a polygon of land use j and n is total number of land use categories. The components of p_{ij} are p_i , the probability that a randomly chosen polygon belongs to patch type i (estimated by the proportion of patch type i), and $p_{j/i}$, the conditional probability, where N_{ij} is **the number** of joins between polygons of patch types i and j , and N_i is the **total** number of joins between polygons of patch type i and all patch types (including patch i itself). RC stands for relative contagion. Values for RC lie between 0 and 1.

Contagion indices are normally computed on (square or rectangular) pixel based images. Joins are based on the four neighboring pixels. Since survey plots represent **Thiessen** polygonal areas, this application is a departure **from** the normal procedure. No effort was made to weight the count of joins based on join length or other suitable procedures. This is a refinement that should be looked into further.

Variance

While the above index is not new, the variance of RC has never been worked out. Using a similar approach as that used by **Basharin** (1959) for the variance of **the** classic entropy index, the variance of RC can be shown to be:

$$V(RC) = 1/2N \ln(n) \{ \sum \sum p_{ij} \ln^2(p_{ij}) - [\sum \sum p_{ij} \ln(p_{ij})]^2 \} + O(N^{-2})$$

where N is number of plots and $O(N^{-2})$ is a remainder term of order of magnitude $1/N^2$. It can be shown that as N tends toward

infinity the distribution of **RC** converges to the normal distribution. For those interested in the details of the variance derivation and distribution properties, please write to the **first** author.

Hypothesis Testing

Because an expression for the variance is available, and the distribution of the contagion index is normal (under large sample sizes, which we have), rigorous hypothesis testing can be accomplished through application of one-way analysis of variance (**ANOVA**). One-way **ANOVAs** can be constructed as follows: let **t** = number of groups, and **T_i** = number of observations for the **i**th group, then:

among groups, variance =

$$\sum_{i=1}^t (RC_i - \overline{RC})^2 / (t - 1); \overline{RC} = \sum_{i=1}^t T_i RC_i / \sum_{i=1}^t T_i$$

within groups, variance =

$$\sum_{i=1}^t T_i V(RC_i) / \sum_{i=1}^t T_i$$

F = among groups variance / within groups variance with **t-1**,

ΣT_i - t degrees of freedom

The formula just given for within groups variance is a pooled estimate of the common variance. If variances are not equal then weighted **ANOVA** should be used. In such a case, divide each **RC** value by the square root of its variance and compute among groups variance. Within groups variance is now 1, hence **F** reduces to among groups variance on the weighted **RC** values.

RESULTS AND DISCUSSION

It is generally believed that prior to the **1900s** forested landscapes in the South were more homogeneous and contiguous than today. Exploitative logging, agriculture, forest type conversion, and other factors have altered, and continue to alter, the mosaic of forest cover types on the landscape. Today landscape flux (changes in **composi-**

TABLE 2. Contagion diversity values, variance and F-tests

Province	Year	RC	V(RC)
Great Appalachian Valley	1972	0.10495	.00049116
Great Appalachian Valley	1982	0.07092	.00036146
Great Appalachian Valley	1990	0.15306	.00069026
Blue Ridge-Talladega Mt.	1972	0.11693	.0015349
Blue Ridge-Talladega Mt.	1982	0.11700	.0014719
Blue Ridge-Talladega Mt.	1990	0.144337	.0010133
Piedmont	1972	0.15522	.00032129
Piedmont	1982	0.06879	.00025456
Piedmont	1990	0.21527	.00060121
HO: For Appalachian	RC ₇₂ = RC ₈₂ = RC ₉₀ ;	F = 3.324,	Prob = 0.036
HO: For Blue Ridge	RC ₇₂ = RC ₈₂ = RC ₉₀ ;	F = 0.188,	Prob = 0.829
HO: For Piedmont	RC ₇₂ = RC ₈₂ = RC ₉₀ ;	F = 13.80,	Prob < 0.001
HO: For 1972	RC _A = RC _B = RC _P ;	F = 9.287,	Prob < 0.001
HO: For 1982	RC _A = RC _B = RC _P ;	F = 0.447,	Prob = 0.640
HO: For 1990	RC _A = RC _B = RC _P ;	F = 5.212,	Prob = 0.006

tion and/or configuration) can occur on the time scale of a decade, as is readily seen in Figure 3 and Tables 2 and 3.

All **RC** values in Table 2 are fairly low, reflecting the fact that all three landscapes have many patches. Compositional change, in terms of changing proportions of forest cover types (see Table 3), is probably more responsible for the differences in **RC** values than configuration, except on the Piedmont. From the tests of hypotheses in Table 2 we can see that there was a significant increase in contagion in the Great Appalachian Valley in 1990 over the years 1982 and 1972. For the Blue Ridge-Talladega Mountain the increase in contagion for 1990 was not significant but in the Piedmont the contagion values were significantly different and followed a quadratic trend; up in 1972 then down in 1982 but with a notable rise in 1990. For the survey period 1972 the Piedmont had greater conta-

TABLE 3. Proportion of each forest cover type on each **province** by **survey year**

Forest cover type	Great Appalachian Valley			Blue Ridge-Talladega Mt.			Piedmont		
	72	82	90	72	82	90	72	82	90
	----- values in percent -----								
Non-forest	2.5	3.6	1.1	4.7	3.9	0.8	2.1	3.3	1.2
Longleaf-slash pine	33.2	28.5	8.3	39.1	37.5	10.5	27.2	23.9	7.4
Loblolly-shortleaf pine	13.7	14.6	24.8	11.7	10.9	22.6	19.7	17.6	24.0
Oak-pine	20.9	20.1	18.8	15.6	18.0	21.8	20.0	20.9	19.9
Oak-hickory	11.6	14.2	36.5	10.9	10.9	33.8	12.8	15.5	36.8
Oakgum-cypress	18.1	19.0	10.5	18.0	18.8	10.5	17.9	18.8	10.4
Elm-ash-cottonwood							0.3		
Nontyped									0.3

gion over the other provinces but in 1982 all provinces had similar contagion. In 1990 the Piedmont again clearly had greater contagion than the Great Appalachian Valley or Blue Ridge-Talladega Mountain Provinces. From these tests we can generally conclude that (1) contagion is up in 1990, **that is**, landscape scale diversity has improved over the last decade and (2) the Piedmont Province has greater contagion (is less fragmented) than the other two provinces.

On all three/landscapes there is a drastic loss (from 72 to 75 percent) of the longleaf-slash pine forest type between 1972 and 1990 (Table 3). The loblolly-shortleaf type appears to double in the Appalachian and Blue Ridge provinces while in the Piedmont it increases by about 20 percent. The oak-hickory type appears to triple across all provinces while the oak-gum-cypress type is dropping around 40 percent on the three provinces. From Figure 3, the oak-hickory and loblolly-shortleaf types are seen to occupy much of the former longleaf-slash and oak-gum-cypress types. In the southern U.S. **longleaf** pine had lost favor because of its "grass stage" where there is little aboveground growth for 3 to 6 years or more. Unfortunately, the other southern pines are more susceptible to **fusiform** rust disease, and species like the endangered red-cockaded woodpecker (*Picoides borealis*) prefer **longleaf** pine over the other southern pines. Prescriptions for hastening the passage through the grass stage have been developed and regeneration techniques have now been well documented (Barnett et al. 1990). Through the use of GIS, landscape views such as Figure 3 will allow foresters and forest managers to see precisely where **longleaf** previously thrived. This should aid in efforts to **re-establish** the **longleaf** resource.

Configuration, the other component of landscape diversity, is undergoing subtler changes. For the three physiographic provinces the pattern appears random, forest cover types occur in small (relative to the landscape) well intermixed patches. On the Piedmont there is more aggregation in 1972 and 1990 than in 1982, hence the low **RC** value in 1982.

A host of tools are today available to policy makers and forestry practitioners to assess the state of forests and to help guide in their management for sustainability. In dealing with landscape or regional scales of resolution, GIS and landscape indices are important tools for characterizing and comparing landscape diversity.

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